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Marine Pollution Bulletin 46 (2003) 1032–1034
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Note

Future aquatic nutrient limitations

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Abstract

Nutrient limitation of phytoplankton growth in aquatic systems is moving towards a higher incidence of P and Si limitation as a result of increased nitrogen loading, a N:P fertilizer use of 26:1 (molar basis), population growth, and relatively stable silicate loading. This result will likely alter phytoplankton community composition, and may compromise diatom → zooplankton → fish food webs.

Keywords: N; P; Si; Element ratios; Eutrophication; Nutrient loading; Global change

1. Introduction

The concentration and elemental ratios of N, P and Si are known to strongly influence phytoplankton communities (Harris, 1986). Empirical expression of these limitations are Redfield ratios (atomic ratios of N:P:Si::16:1:16), which are the stoichiometric requirements for balanced growth (Redfield, 1958; Justic' et al., 1995; Elser et al., 1996). Strong deviations from these ratios indicate that the nutrient in lesser supply becomes limiting for phytoplankton growth if a minimal amount is available. These ratios in rivers are changing as the loading of N, P and Si is influenced by human activities.

Human activities have such a strong influence, in fact, that the global variations in the loading of both P and N from watersheds to oceans can be described satisfactorily using simple land use categories, population densities and fertilizer use (Caraco, 1993; Howarth et al., 1996). The present (circa 2000) annual agricultural applications of N and P are equivalent to 242% and 83%, respectively, of the annual global riverine fluxes (Schlessinger, 1991) and are expected to double in the next 50 years (Table 1). The present consumption of N fertilizer is 26 times greater than for P, far exceeding the 16:1 ratio required for balanced phytoplankton growth. The applied N leaks from land to water mostly as the highly mobile nitrate ion. Some P may accumulate in soils (Bennett et al., 2001). As a result, the concentration of various forms of N and P in fresh waters are increasing throughout the world (e.g., Cloern, 2001). In contrast to N and P, however, the global variations in silicate loading from rivers are predominantly controlled by its geochemistry, latitude and runoff, although silicate concentrations may be reduced by as much as 50% due to hydrologic changes in the watershed (Correll et al., 2000; Humborg et al., 2000). The observed and predicted global increases in N and P loading, and the relatively stable or lower Si loadings have, therefore, a potential to strongly influence dissolved N:P:Si ratios in rivers, hence aquatic food webs.

We reviewed data for dissolved inorganic nitrogen, dissolved inorganic phosphate and dissolved silicate (DSi) in the world's largest rivers and plot these in a way that illustrates the present patterns and implies future nutrient limitations, assuming the predicted increases in N and P fertilizer use occurs.

2. Methods

The data are described in Turner et al. (in press). These data are part of a Global Environmental Monitoring System (2000) monitoring program for the world's largest rivers that includes 44% of the Earth's land mass (exclusive of the Antarctic) and half the Earth's population. The cumulative average annual

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0025-326X/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0025-326X(03)00049-3

Table 1
Present and future world fertilizer production (less USSR) as N and P (P as P_2O_5) as estimated by Tilman et al. (2001), and the equivalent N:P molar ratios

Year	10^6 MT fertilizer		N:P molar ratio
	N	P as P_2O_5	
2000	6.2	0.24	25.7
2020 (estimated)	9.6	0.34	28.7
2050 (estimated)	16.9	0.6	28.6

discharge of these rivers is 20,295 $km^3\ year^{-1}$. The data are from 66 countries and were collected between 1976 and 1995. Some station data represents monitoring for only 2 years. Differences in the seasonal variations in nutrient ratios among rivers are not revealed using annual averages. We calculated the mean N:P and Si:N ratios (molar basis) for the dissolved inorganic constituents and plotted them as a log:log plot. The data were divided into three groups (or clusters) distinguished by the average nitrate concentration: <7, >7 and <100, and >100 μM. The Redfield ratios for N:P and Si:N were overlaid on this plot, and the four quadrants labeled according to the potential for N, P, N + Si, or Si + P limitation of phytoplankton growth.

3. Results and discussion

The results indicate that lotic systems are moving towards lower Si:N and higher N:P ratios as nitrate concentrations increase (Fig. 1). Both P and Si limitation is favored as nitrate concentrations increase to above 100 μM. The coastal areas most likely to now have both P and Si limitation are in northern Europe and the northern Gulf of Mexico. Through nutrient limitation on growth, these changes affect phytoplankton dominance, their consumers, and determine alternative community states that may include harmful phytoplankton blooms (Officer and Ryther, 1980; Smayda, 1990). For example, diatoms use Si in their external frustules, and if the Si:N ratio is below 1:1, diatoms may be replaced by diatoms with less silicified frustules or with non-diatoms and the diatom → zooplankton → fish (DZF) food webs will be compromised (Turner et al., 1998; Dortch et al., 2001). These changes may lead to the formation of alternative, if not harmful, algal communities (Smayda, 1990; Rocha et al., 2002; Rousseau et al., 2002). The general pattern of N, P, and Si loading to estuaries and coastal waters under the lower nitrate concentrations of the last century indicates the prevalence of N over P limitation. P and Si limitation appears to be developing as symptoms of eutrophication increase concurrent with higher nitrate loading, including noxious blooms and increasing incidences and severity of hypoxia. In summary, nutrient management in coastal waters in this century must take into account not only the effects of increasing amounts of various nutrients, but also their relative proportions and, importantly, anticipate future compromises of the DZF food webs.

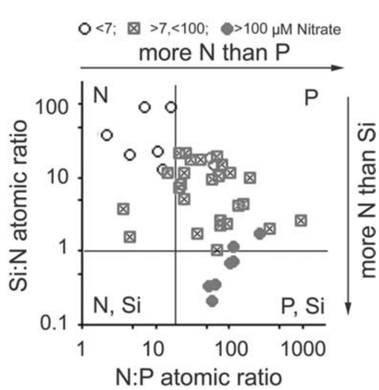

Fig. 1. The molar ratios of DSi and nitrate (Si:N) and dissolved nitrate and phosphate (N:P) in large rivers of the world. Data are described in Turner et al. (in press). The Si:N and N:P atomic ratios of 1:1 and 16:1 are indicated by the horizontal and vertical lines, respectively. Nutrient limitation (assuming sufficient concentration) within each quadrant are indicated by the lettering.

Acknowledgements

This research was funded by grants from the National Oceanic and Atmospheric Administration (NOAA), Coastal Ocean Program.

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